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THE UNIVERSITY OF CHICAGO MEASUREMENT IN SPACE OF COSMIC RAYS AT ENERGIES ABOVE 0.5 MEV*

OTS PRICE

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Introduction

Since 1958, two groups[1] at The University of Chicago have collaborated in designing several experiments to acquire information relating to the flux of primary cosmic rays having energies normally below the threshold imposed by the geomagnetic field. These experiments are performed with instruments carried by space vehicles. So far in this program, two types of cosmic-ray counter telescopes have been designed and built.

The first type includes a three-fold coincidence counter which has a low-energy threshold for protons at about 75 mev. Such instruments have been flown successfully aboard Explorer VI and Pioneer V. From these flights much useful information was obtained regarding the radiation belts,[2] the Forbush decreases,[3] the solar acceleration of protons,[4] and the gradient of the cosmic-ray flux as a function of distance from the sun.[5] Another instrument of this type is similar to the first but has a lower threshold, 10 mev. The third, which is based upon a different principle, is a two-element, solid-state device[6] for measuring the flux at energies from 0.5 to 10 mev. The latter two instruments are scheduled for first flight aboard a high-eccentricity, earth satellite in late 1961 or early 1962.

This paper contains a detailed description of the first type of telescope. All the instruments of this type are alike except for the detector systems.

The Three-Fold Coincidence Telescope

The three-fold coincidence telescope, shown schematically in Fig. 1, consists of seven semi-proportional counter tubes, each half an inch in diameter and three inches long, arranged in a closely packed hexagonal array of six tubes surrounding the seventh. The outer tubes are connected in two groups of three each, while the center tube forms the third element.

The third element measures the flux of electrons and low-energy gamma radiation in the "soft" background so that the triple coincidences accidentally caused by these particles can be separated from those actually arising from the primary high-energy beam. The output of this center tube is a measure of the bremsstrahlung due to electrons in the energy range 0.2 to 13 mev. The bremsstrahlung is strong in regions such as the outer radiation belt. The number of accidental triple coincidences, N, is related to the count recorded by the center tube, N_c, in the formula

$$N = 27\tau^2 N_c^3 ,$$

where τ is the coincidence gate time constant.

The energy threshold for charged particles is fixed by the choice of the counter tube wall and the surrounding shield. For example, the 75-mev cutoff system has brass counter tubes with 0.030 inch thick walls enclosed by 5 grams of lead per square centimeter of wall, while the 10-mev cutoff is obtained with stainless steel tubes with 0.002 inch thick walls, unshielded.

The high-voltage supply associated with the telescope (Fig. 2) consists of a transistorized multivibrator driving the primary winding of a transformer, a full-wave rectifier-multiplier for multiplying the transformer output voltage by a factor of eight, a filter, and a voltage regulator tube. The supply draws 27 milliwatts from a 6-volt d-c source and delivers 5×10^{-6} amperes at a voltage selected to conform to the plateau characteristics of the telescope (2200 to 2500 volts). The filter is a critical component because it must keep the ripple and noise in the power supply below the 1-millivolt threshold of the amplifier-discriminator system to prevent spurious counts. To prevent noise input during periods of corona loss, which may occur at high altitudes, for example, the entire high-potential portion of the system is encased in an epoxy resin applied by a vacuum impregnation technique to prevent bubbles, which are potential leakage paths.

Amplifier-Discriminator

Each of the three coincidence elements of the detector telescope is connected to a separate amplifier-discriminator channel. The threshold of each channel is set so that a 1 millivolt input pulse, which is a signal about an order of

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CR-50,582

magnitude greater than the noise output of the detector, will produce a shaped output pulse approximately 6 volts in amplitude and 1 microsecond wide at 10 per cent height above baseline.

The amplifier consists of four transistor circuits; an impedance-matching stage in the input, two gain stages with a nominal over-all gain of 125, and another impedance-matching stage in the output.

The discriminator consists of a two-transistor, one-shot multivibrator with an additional transistor on the input to accelerate the turn on action, thus providing a shorter rise time of the output pulse without requiring transistors faster than those being used in the rest of the circuits.

Temperature compensation is accomplished by using silicon resistors in critical locations to correct the silicon transistor parameter variations with temperature. The arrangement takes advantage of the fact that variation in amplifier gain with temperature compensates for change in discriminator threshold with temperature. The input sensitivity or threshold of an amplifier-discriminator channel holds to within $\pm$ 10 per cent over a temperature range from -35°C to +55°C and a supply voltage variation from 4.5 to 7.5 volts. The amplifier-discriminator channels show no tendency to double pulse up to signal inputs of 5 volts. The schematic for the amplifier-discriminator is shown as Fig. 3.

Triple Coincidence Gate

The outputs of the three amplifier-discriminator channels are connected to the three inputs of the coincidence gate. When a particle is energetic enough to penetrate all three coincidence elements of the detector telescope, a small negative pulse appears at the input of each of the three amplifiers. Each pulse is amplified and applied to the discriminator in its channel. If the pulse from the amplifier exceeds the discriminator threshold, the discriminator emits a pulse of a standard height and width. Since time of flight through the elements of the telescope is extremely short, if there are pulses from the three discriminators to the three inputs of the coincidence gate, they will be in time coincidence and there will be an output from the coincidence circuit.

The coincidence circuit itself consists of three cascaded PNP silicon transistors in the input circuit and a single NPN silicon transistor in the output driver circuit. The circuit requires a minimum pulse of 0.6 volt on each of its three inputs to operate. The circuit requires minimum power since the transistors are essentially off until there is a three-fold coincidence event. The schematic for the circuit is shown in Fig. 4.

Scalars

There are two independent scalar channels, one driven from the output of the coincidence circuit and the other from the amplifier-discriminator channel that connects to the center tube in the detector telescope. The number of stages per scalar binary is dictated by the vehicle's mission and the capability of its telemetry.

A conventional scalar binary circuit with diode steering is employed. Since the power drawn by a binary is dependent upon the maximum rate at which it is capable of operating, the binaries in the scalar are graded according to operating speed to conserve power. The faster binaries are used in the front end of the scalar, followed by the medium-and low-speed binaries, which extend to the end of the scalar. Typical scalar channels are shown schematically in Fig. 5.

Output Circuits

The output circuits are dictated by the telemetry requirements of the space vehicle. These range from a simple emitter-follower circuit that couples the transition of the output stage of a scalar into the subcarrier oscillator of a simple real-time FM/FM telemetry system, to circuits that provide pulses of a particular pulse-height, width, and polarity to a digital storage system. For those vehicles in which the number of data channels has been restricted, other output circuitry has been used to multiplex both scalar outputs on a single data channel.

Calibration

The calibration of the instrument consists of two main phases:

1. Calibration of the individual components of the detector telescope.
2. Calibration of the completed assembly.

Plateau characteristics which occur between 1900 and 2300 volts have been found in the individual counters. In general, the plateau is from 100 to 200 volts wide. After the counters have been individually calibrated, they are matched in groups of seven tubes which have plateau centers within a 5- to 10-volt range. The power supply is then matched to the group.

After selection of the seven tubes has been completed, the group is clustered similarly to the way in which they will operate in the completed telescope. Plateau characteristics of the combination are then determined and matched to a voltage regulator tube and high-voltage supply. At this point the telescope is assembled with its high-voltage supply. After a final calibration to verify satisfactory operation of the telescope system, the assemblies are potted with Fuller Brothers Resiweld, to prevent corona loss during low residual pressure operation. The telescope assembly is then mated with the electronics.

The complete detection system is then tested by mointoring the background cosmic-ray count. For this phase of the calibration the location and orientation of the telescope are found to be critical. Therefore, each instrument is tested in the same location and orientation for the background run. A counting period of from 24 to 48 hours is allowed to obtain the desired statistical accuracy. The count rate experienced during this operation is from 3 to 4 counts per minute in the three-fold coincidence channel and from 10 to 12 counts per minute in the single channel. Counts pro duced in the three-fold coincidence channel are primarily due to the flux of mesons in the cosmic-ray beam. Further extended background counts are obtained before the system is installed in the spacecraft. These background runs have been found to be necessary because of the variation in background as a function of geographic location as well as laboratory environment. It is now possible to relate the background counting rate encountered during extended systems tests of the spacecraft to the background counts obtained in the laboratories at Chicago.

Abstract

Summary

18858

The three-fold coincidence telescope is a compact, flexible instrument providing cosmic-ray measurements related to the charged-particle flux at a well-defined low-energy cutoff. The output to the space-crafts data-handling system may be in either analog or digital form. The experimental results to date have provided useful information of the space environment at distances from 200 miles to some 22 million miles from Earth.

Acknowledgment

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The detailed requirements of performance for the instrument were obtained through the guidance of C. Y. Fan, Peter Meyer, and John A. Simpson of The University of Chicago's Enrico Fermi Institute for Nuclear Studies, while the design, assembly, and testing of the instrumentation was performed by J. E. Jezewski, R. M. Takaki, W. E. Six, D. L. Gilbert, H. Tibbs, J. Stepney, G. Shimotori, and others at the Laboratories for Applied Sciences. Counter tubes were assembled and filled by the N. Wood Counter Laboratories.

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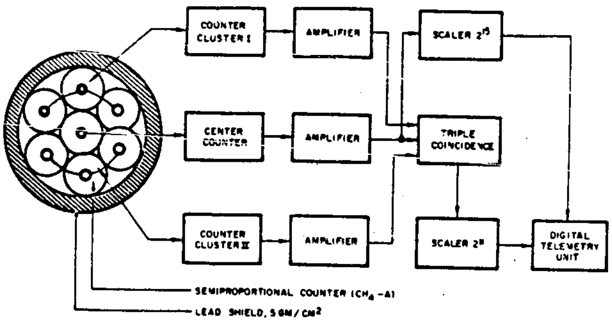
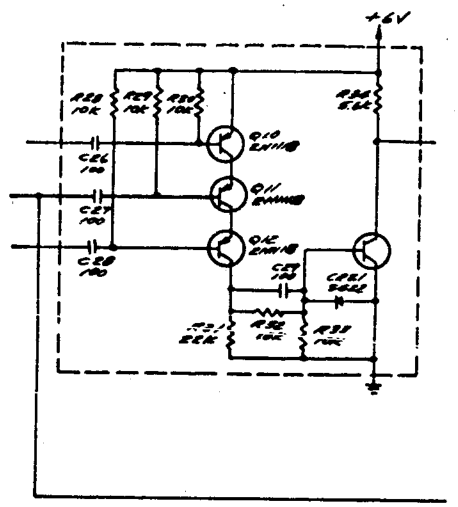
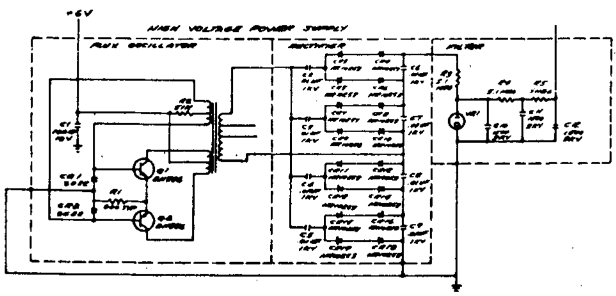
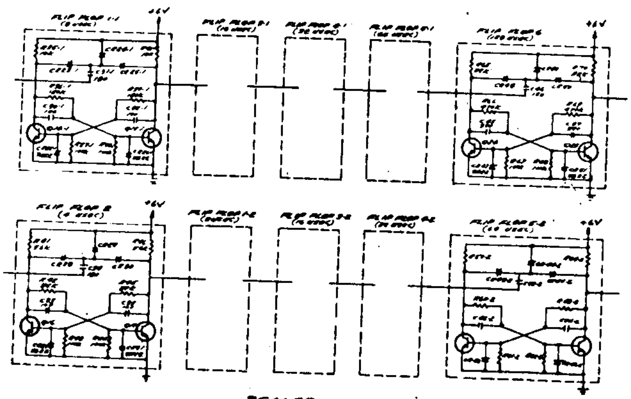


Figure 1. High Energy Charged Particle Instrumentation



TRIPLE COINCIDENCE





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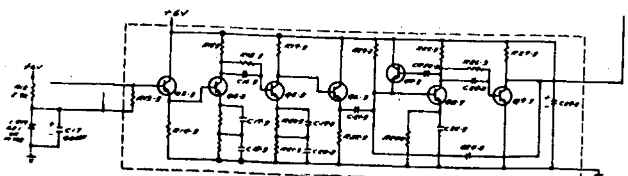

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